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MODIFICATION
of
INTEGRATED PARTIAL PAYLOAD LIFTING ASSEMBLY

FINAL REPORT

(NASA-CR-182573) MODIFICATION OF INTEGRATED PARTIAL PAYLOAD LIFTING ASSEMBLY Final Report (University of Central Florida) 30 p CSCL 22B

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Submitted to:
DR. ANDERSON
EML 4505
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Submitted by:
MELODIE GROAH
MICHAEL HADDOCK
WARREN WOODWORTH

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EXECUTIVE SUMMARY

The Integrated Partial Payload Lifting Assembly (IPPLA) is currently used to transport and load experimental payloads into the cargo bay of the Space Shuttle. It is unable to carry the astronaut/passenger tunnel without a structural modification. The purpose of this student design is to create a removable modification that will allow the IPPLA to lift and carry the passenger tunnel. Modifications evaluated were full-length insert beams which would extend throughout the existing strongback arms. These beam proposals were eliminated because of high cost and weight. Other proposals evaluated were attachments of cantilever beams to the existing strongback arms. The cantilever proposals reduced cost and weight considerably compared to the full-length modifications. A third method evaluated was to simply make modifications to one side of the IPPLA therefore reducing the materials of the cantilever proposals by 40 percent. The design of the modification selected was completed with two channel beams jointly welded to a centered steel plate. All welds between the channels and the steel plate are made at the channels' opened ends. The extension arm modification is inserted into the existing strongback channel beams and bolted into place. Two extension arms are added to one side of the IPPLA to provide the extra length needed to accomodate the passenger tunnel. The center counterbalance will then be offset about 20 inches to center gravity and therefore maintain horizontal status. This horizontal status is a necessity for proper loading of the astronuat tunnel. The extension arm modification was selected because of minimum cost, low weight, and minimal installation time.

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INTRODUCTION

The National Aeronautics and Space Administration (NASA) has supplied a request to increase lifting capability of the Integrated Partial Payload Lifting Assembly (IPPLA). The device, at this time, successfully serves as a lifting medium by which actual payloads are loaded into the cargo bay of the U.S. Space Shuttle. The basic need of this entire project is to make IPPLA completely universal. Currently, the function of IPPLA, also referred to as the "white whale", is limited because it is incapable of lifting the astronaut tunnel that leads from the crew cabin to the cargo bay. The device that NASA presently uses to load the astronaut tunnel is referred to as a strongback. In order to use the strongback, NASA must use three engineers, twelve techicians, and two crane crews. NASA wishes to use the white whale which would only require one engineer, four technicians, and one crane crew. The white whale would also do the job in a fraction of the time that the strongback could. The strongback requires two working days or sixteen hours to do the job whereas the white whale could complete the job in two hours.(Ref. 1)

The white whale will have to be modified with removable parts in order to accommodate the passenger tunnel and still continue to do the job it was designed to do, which is to load pallets and Mission Peculiar Experiment Support Structures (MPESS) containing space-bound experiments. In short, modification to the design problem will save NASA fourteen working hours, reduce manpower by twelve and at an average pay of about $30/hr will save $5040/loading of the passenger tunnel.(Ref.1)

DETERMINING MEANS

The following ideas all serve as probable solutions to the modification of IPPLA. All modifications are being directed toward the lowermost portion of the white whale known as the strongback channel beam. Modification ideas cover a range that varies from the insertion of solid symmetric beams to the coupling of an asymmetric square beam sleeve.

The IPPLA solutions have been categorized into two main groups; full-length and cantilever beams. The full-length beams extend throughout the entire length of the strongback channel whereas the cantilever beams only extend through a portion of the channel.(Table 1)

The four proposed solutions in the full-length beam category show the greatest strength of all other designs, but the drawbacks are the cost, weight and size. One proposed solution is a solid beam which exhibits the highest strength but also has the highest cost and weight.(Fig. 1) The disadvantage of weight and size would affect installation, portability and labor cost. An improvement on the design above leads us to the proposal of full-length channel beams which could decrease weight by 78.5% and therefore dramatically decrease cost at $0.75/lb of steel.(Ref. 1) The I-beam and worm gear are simple modifications to the previous two designs. The worm gear mechanism (Fig. 2) is used in a hand cranking fashion to stablize the inserted beam which would improve installation and stability.(Ref. 2) As an alternative, an I-beam design (Fig. 3) was proposed that would distribute the tunnel load over the top of the modified extensions, therefore relieving a portion of the load on the securing bolts. Even though the modifications in this group could successfully solve our problem, further study has shown that other proposals will yield even better results.

The second of the two solution groups is that of cantilever beams. Two divisions within this group have been termed symmetric and asymmetric. All symmetric designs will not offset IPPLA's center of gravity. The asymmetric modifications will require use of the existing counterweights to balance the lifting assembly.

The symmetric subgroup contains five proposals. First, hinged extensions with the addition of supporting cables (Fig. 5) was considered because of its portability and weight. Second, a simple insertion of cantilever beams with the use of cables (Fig. 4) may increase strength over the hinged mechanism but it would also increase weight. By eliminating the support cable, cost would decrease slightly with minimal strength lost. The third and fourth modifications could be accomplished by insertion of channel or solid cantilever beams. The channel insertion proves to be dominant due to relatively low weight and cost. A fifth but similar solution is that of a square beam sleeve which would slide over the existing arms of the strongback channel beam. Advantages of the square sleeve include a close fit over the strongback channel beams and an increased moment of inertia resulting in lower stress.(Ref. 3) Once again, the modifications of the symmetric cantilever subgroup are a great improvement over the full-length beams, yet one final group offers even greater appeal.

The final group of proposals consists of the asymmetric designs. The asymmetric designs are exactly the same as the symmetric, with the exception of length dimensions. The asymmetric designs require presetting of the center counterweight on the main frame because modifications will be made to one side of the IPPLA only.

The advantages and disadvantages of each proposal are weighed in table 2. The full-length beam proposals have been eliminated due to excessive cost and weight. The symmetric cantilever beams will remain as adequate solutions to the problem, yet advantages of the asymmetric solutions appear to be optimal.

SOLUTION OPTIMIZATION

The two most probable solutions to the modification of IPPLA are the sleeve/insert cantilever (Fig. 6) and the hinged/cable cantilever (Fig. 7). Both designs have been selected because of reduced cost, weight, and installation time over all previously mentioned designs. Above all, the advantage of asymmetric design prevails because strength can be maintained while the amount of building material has been reduced by 40%.

Further insight into the hinged proposal shows complications within the hinged mechanism itself. The hinge would have to be tooled from a single billet of structural steel or it would have to be made of materials exhibiting the properties of titanium. The process of wroughting out the hinge from a steel billet is an expensive process.(Ref. 1) Titanium exhibits high strength-to-weight ratio and excellent corrosion resistance but high cost of manufacturing products and extracting from their ores rules out this possibility.(Ref. 4) Due to the hinge's disadvantages, the sleeve/insert beam is preferable. (Fig. 8).

By inspection of Figs. 8 & 9, it can be seen that the chosen design meets the requirement of being removable. A total of six bolts, which provides easy installation with minimal labor, will secure the entire modification to IPPLA. The distance between the supporting rods has to be exactly 121.93 inches to accommodate the passenger tunnel. All geometric dimensions have been accounted for and can be seen in both reference figures 10 & 11. The center of gravity of the entire assembly when loaded is maintained by adjusting the center counterbalance 21 inches to offset the modification. A safety factor of five has been used to ensure safe loading conditions. The complete design has been produced by using a multiple of five times the working weight of the astronaut tunnel or 12,500 pounds. All measures have been taken to meet the above conditions, thus the result shows promise for an optimal solution.

The optimal solution to the design consists of two, forty inch channel beams with a 12 x 24 x 1 inch structural steel plate welded to the open end of the beams. The welds should conform to Kennedy Space Center-Spec-Z-0004, class B.(Ref.5) The steel plate serves as a mount for the main rod assembly. Only sixteen inches of the total modification will be inserted into the existing strongback channel beams. The American Standard Channel beam for this optimal design is a C7 x 9.8, which will require only five hundredths of an inch machining to fit into the existing strongback channel.(Ref. 3) After installation, the surface of the strongback plate and the surface of the modification plate will be in full contact allowing minimal deformation. ASTM-A307 1 5/8 inch diameter bolts will be used to secure the implemented design.(Ref. 6)

The arrangement and the diameter of the bolts were determined with the use of a detailed computer program written in BASIC. (APPENDIX A) The computer program was written to calculate the total shearing and bearing stress on each bolt. The program also calculates the bending and shear stresses within the dual channel beams. Variables within the program include the length of the channel beams, the number and diameter of bolts, the type of channel beams and the bolt configuration. The main computer steps taken to solve for the variables are as follows: (1) input channel type and length, bolt quantity and diameter, and bolt configuration, (2) calculate bolt pattern centroid, (3) calculate total moment about bolt centroid, (4) calculate both direct and moment loads, (5) calculate force components and use superposition to find the resultant force on each bolt. After successive program runs, the optimal bolt configuration was found. (Fig. 9 & APPENDIX B) The only restriction within the program was that of maintaining constant bolt diameters. The restriction allows bolts to be interchangeable upon installation and does not affect the optimal design.

Minimum weight, maximum strength, and low cost are three of the contributing factors that make this design optimal. Another factor is the existence of redundancy in this design. For example, the inserted channel beams have been designed such that they will have little room for play, even before they are secured with bolts. If all three bolts fail under a load, IPPLA could still carry the load safely. Another form of redundancy is the fact that the channels are bolted withing the existing strongback beam that easily supports loads of eight thousand pounds or more. The total weight of the astronaut tunnel is only one ton. The previous considerations provide some of the added features that make the selected modification of the white whale the most attractive of the feasible solutions.

References

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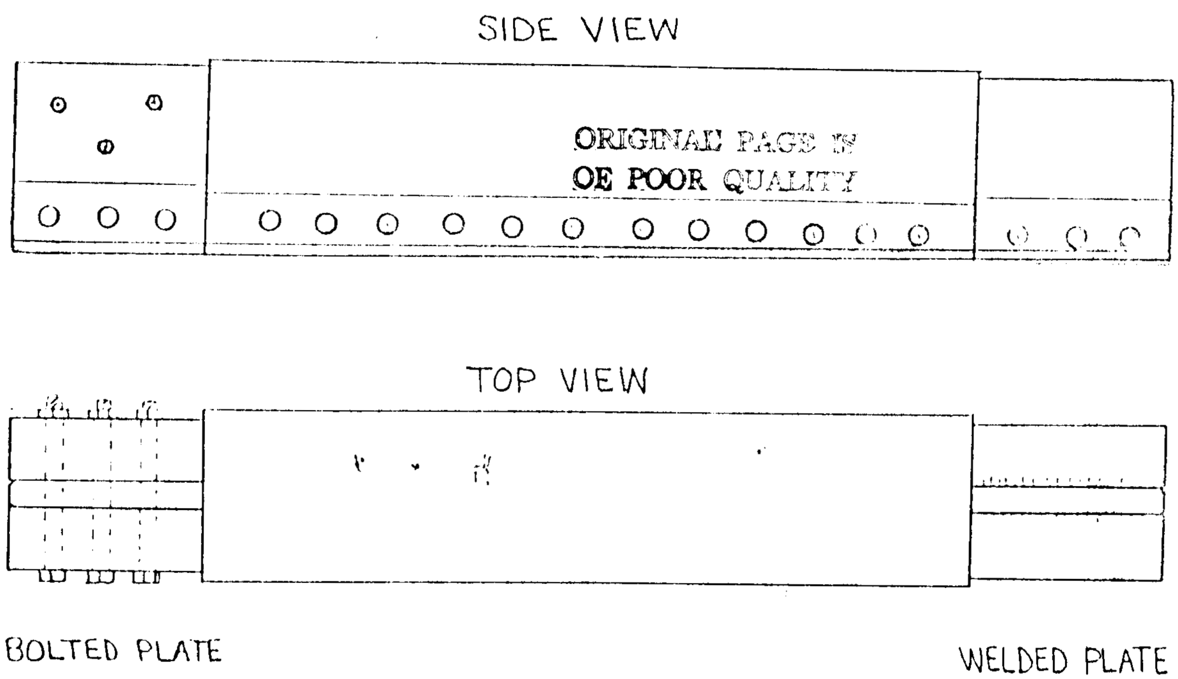
6 Baumeister, Theodore, and Eugene A. Avallone, Marks' Standard Handbook for Mechanical Engineers, McGraw-Hill, New York, 1978.

ACKNOWLEDGEMENTS

A grateful appreciation to Craig Baker at NASA for his encouraging support and insight.

Also, a special thanks to Dr. Loren Anderson at the University of Central Florida for his continuous support.

FIGURES



ABOVE DRAWINGS ARE OF SOLID OR CHANNEL BEAM PROPOSALS (SIMILAR DESIGN)

FIG. 1

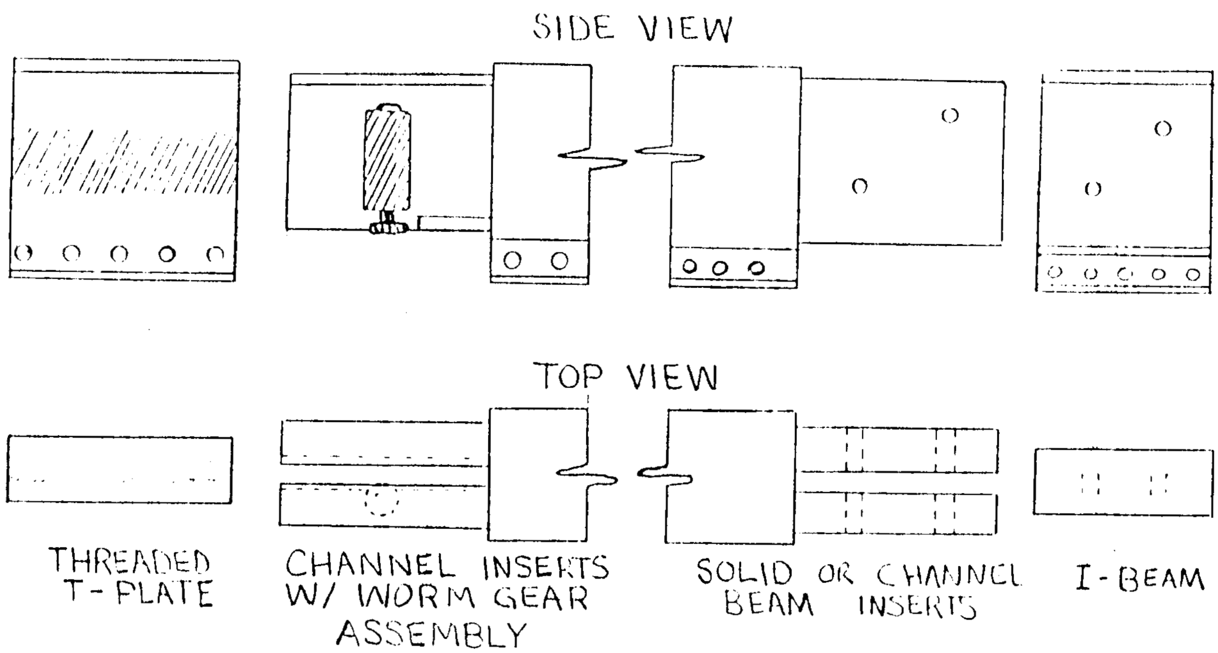
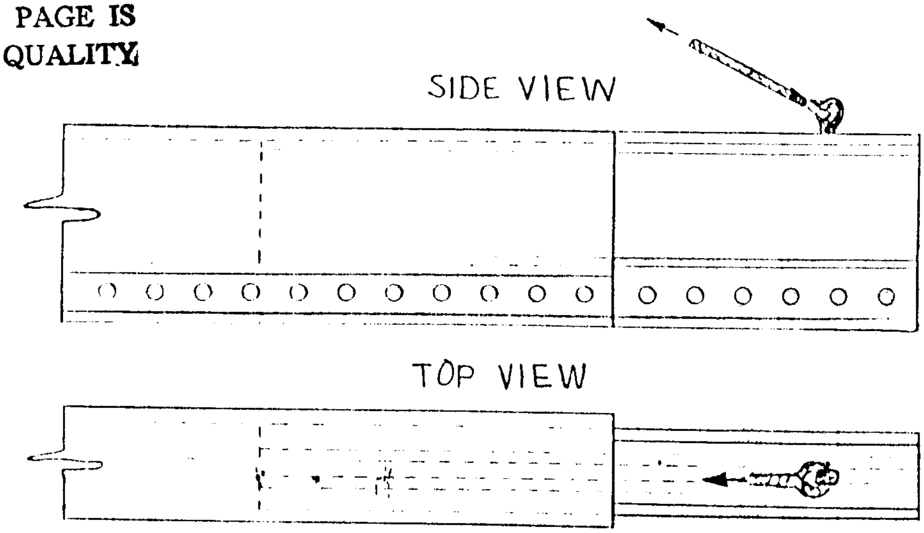


FIG. 2

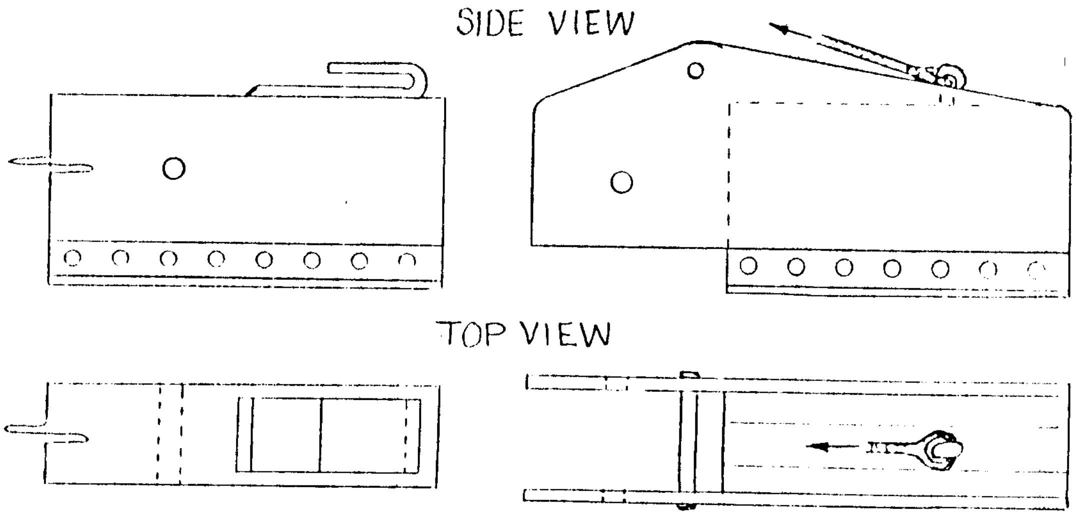
FIG. 3

FULL-LENGTH PROPOSALS



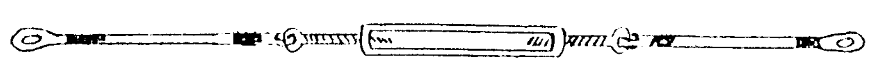
INSERTED CHANNEL BEAM (OR SOLID BEAM)
WITH CABLE FOR ADDED SUPPORT & STABILITY

FIG. 4



HINGE & CABLE DESIGN

FIG. 5



ADJUSTABLE CABLE ASSEMBLY

CABLE - CANTILEVER PROPOSALS

SLEEVE/INSERT CANTILEVER

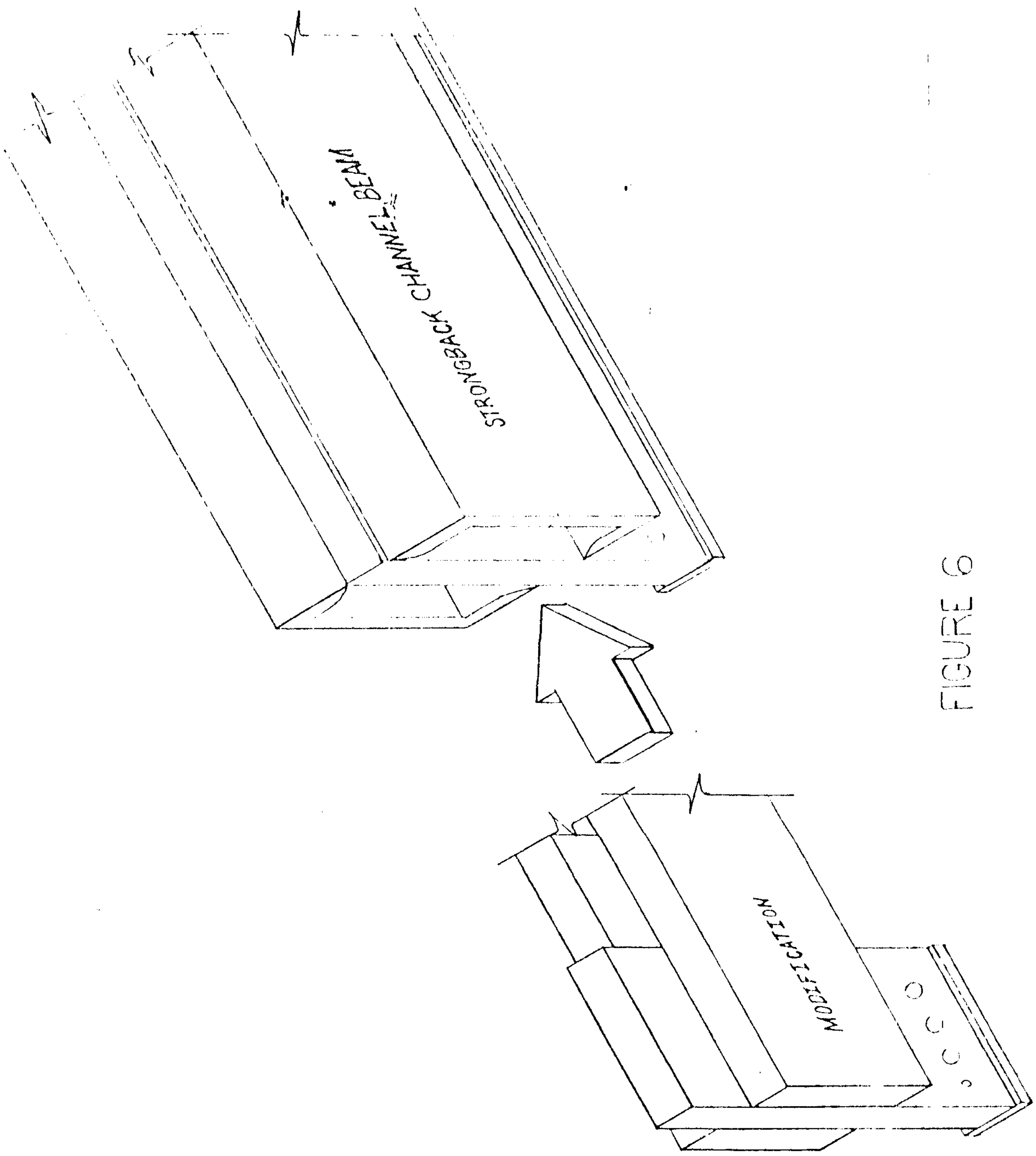


FIGURE 6

HINGED CANTILEVER

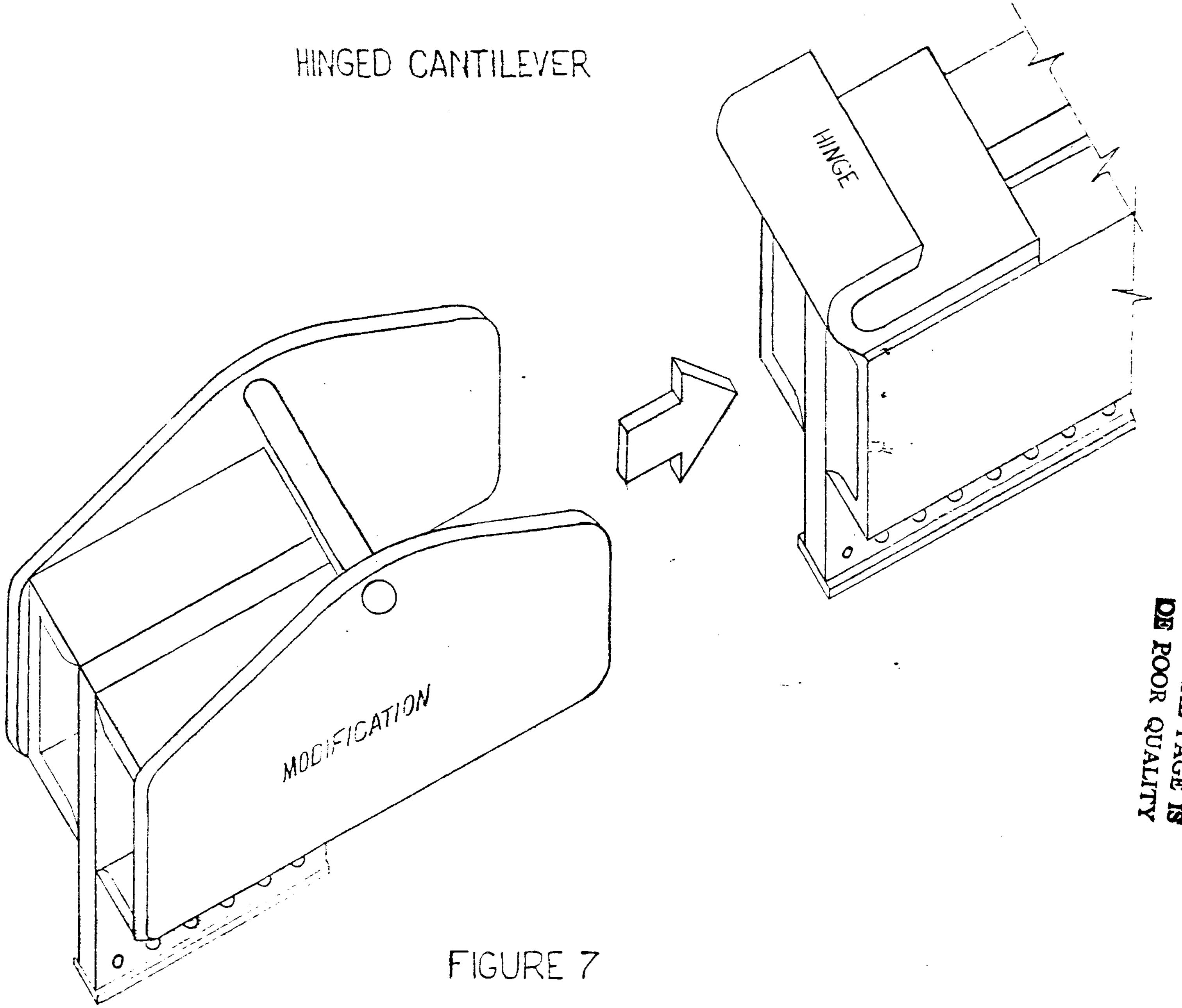


FIGURE 7

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INSERTED DUAL CHANNEL BEAM

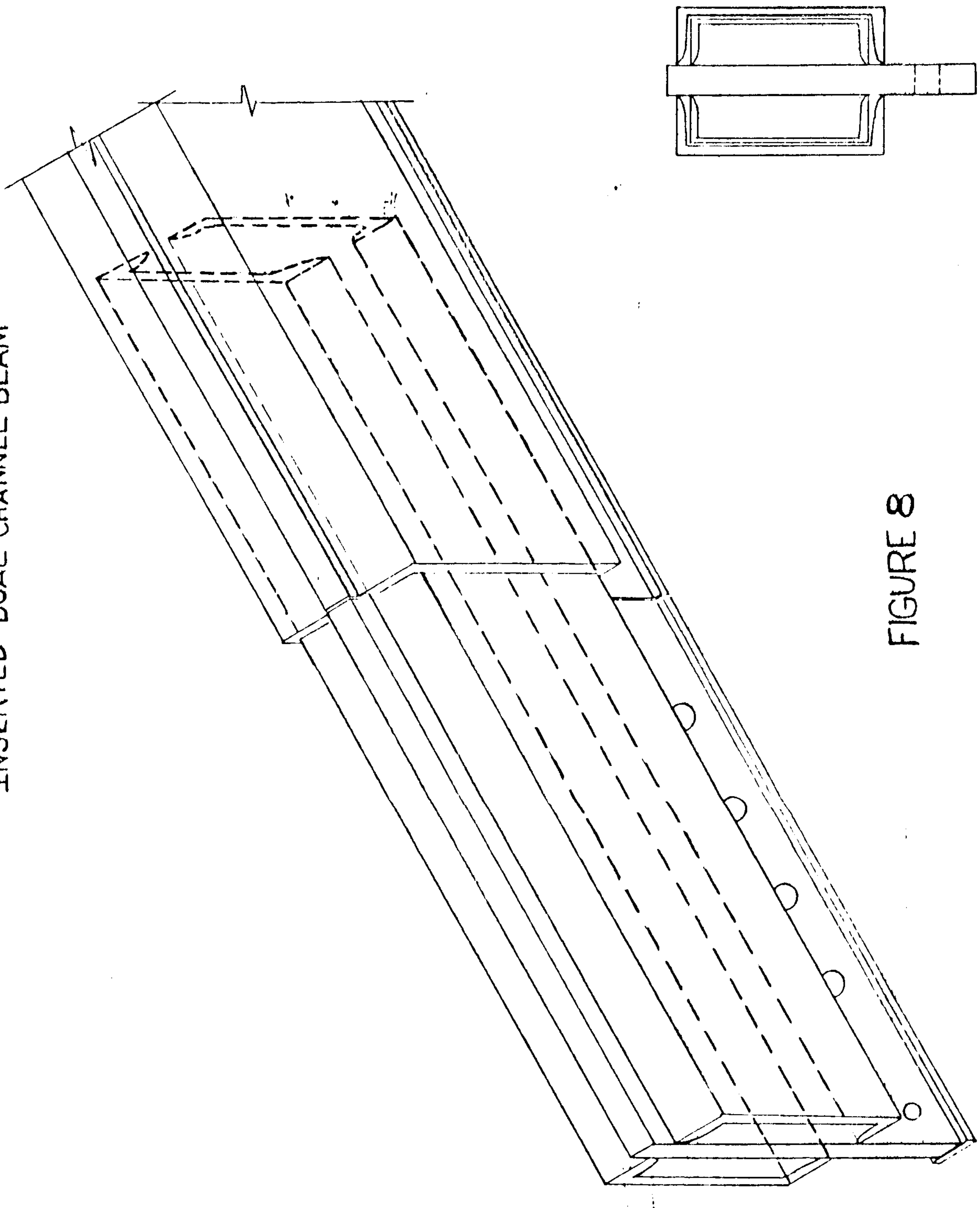
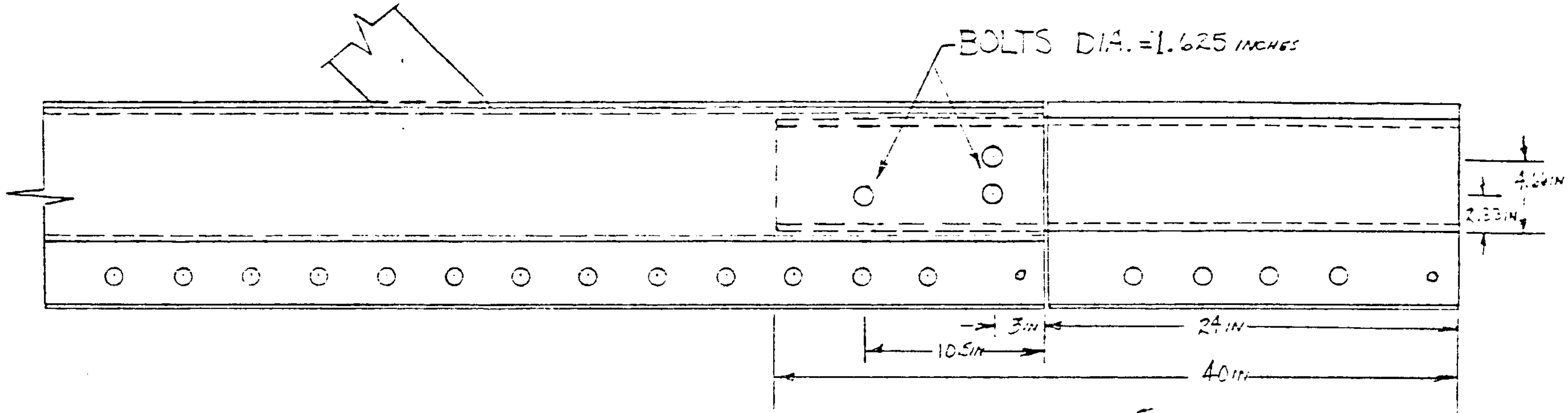


FIGURE 8

1CM=2.4 IN



STRONGBACK BEAM AND MODIFICATION

SIDE VIEW
1CM = 4IN

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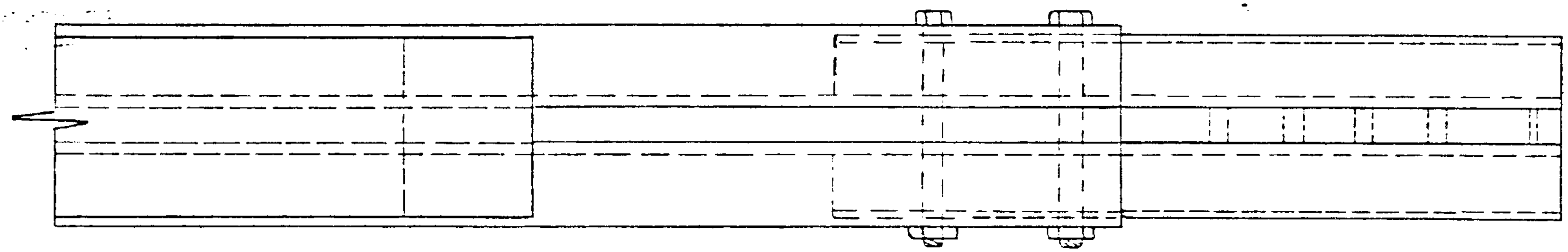

TOP VIEW
1CM=2IN

FIGURE 9

TABLES

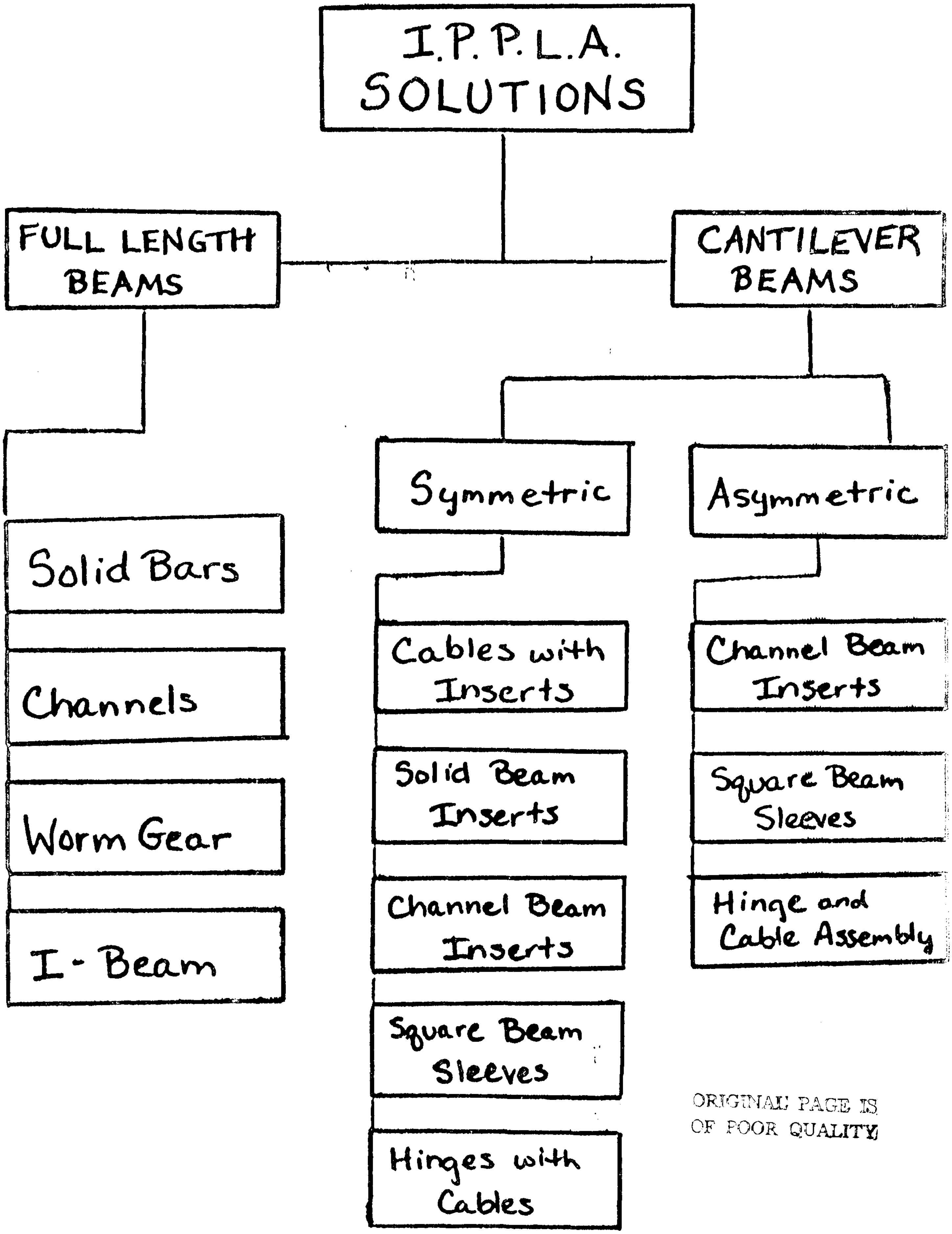
I.P.P.L.A.
SOLUTIONS
FULL LENGTH BEAMS
CANTILEVER BEAMS
Solid Bars
Channels
Worm Gear
I-Beam
Symmetric
Asymmetric
Cables with Inserts
Solid Beam Inserts
Channel Beam Inserts
Square Beam Sleeves
Hinges with Cables
Channel Beam Inserts
Square Beam Sleeves
Hinge and Cable Assembly

TABLE 1

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Problem Solutions	Safety	Cost	Strength	Weight	Reliability	Size	Installation	Portability	Total	Total Possible
Solid bars going all the way through (2)	50	9	40	3.5	30	5	4	3	144.5	260
…rs going all the way through with worm gear (2)	45	18	32	10.5	27	5	10	6	153.5	260
… going all the way …gh with I-beam assembly (2)	45	22.5	32	10.5	27	5	8	6	156	260
…hannel beams going all the way through (2)	45	22.5	32	10.5	27	5	8	6	156	260
…inge assembly with …able attachments (4)	45	31.5	32	24.5	27	20	16	12	208	260
…antilever with …le attachments (4)	50	27	36	21	30	15	12	9	200	260
Solid beam inserts (4)	50	13.5	36	7	30	15	6	4.5	162	260
Channel beam inserts (4)	45	36	28	21	27	15	12	9	193	260
Square beam sleeves (4)	45	31.5	32	21	27	15	12	9	192.5	260
Hinge and Cable Assembly using counterbalance (2)	45	36	32	35	27	25	20	15	235	260
Channel beam inserts using counterbalance (2)	45	45	28	24.5	27	20	16	12	217.5	260
Square beam sleeves using counterbalance (2)	45	40.5	32	24.5	27	20	16	12	217	260

Rating Scale:

5 - Excellent

4 - Very Good

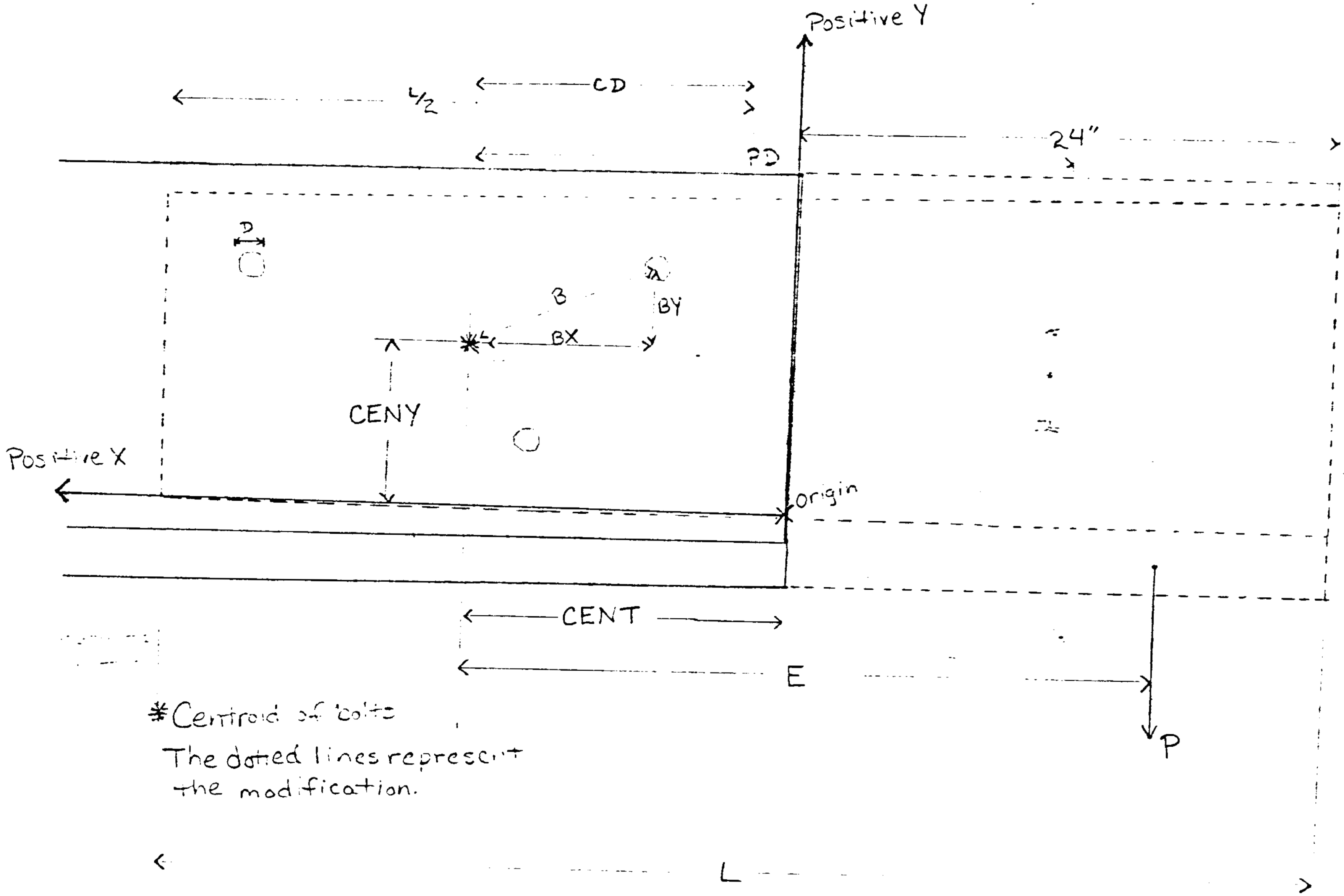
3 - Fair

2 - Below Average

1 - Poor

Each number in the table was computed by multiplying the weight ( ) at top by the number in the rating scale.

APPENDIX A



*Centroid of bolts
The dotted lines represent the modification.

PROGRAM VARIABLES

```
2 REM*****************************
5 REM*     MODIFICATION OF        *
10 REM* INTEGRATED PARTIAL PAYLOAD *
15 REM*     LIFTING ASSEMBLY       *
17 REM*****************************
19 REM
20 REM+++++++++++++++++++++++++++++
25 REM+      SUBMITTED TO:        +
30 REM+     DR. L. ANDERSON       +
35 REM+        FALL 1986          +
37 REM+++++++++++++++++++++++++++++
40 REM
42 REM=============================
44 REM=      SUBMITTED BY:        =
45 REM=    WARREN WOODWORTH       =
46 REM=    MICHAEL HADDOCK        =
47 REM=     MELODIE GROAH         =
48 REM=============================
49 REM
50 LET C=0
53 INPUT "TYPE OF CHANNEL?";C
55 INPUT "LENGTH OF CHANNEL (IN) ?";L
60 INPUT "NUMBER OF BOLTS?";N
65 INPUT "DIAMETER OF BOLTS (IN) ?";D
75 FOR I=1 TO N
80 INPUT "PLACEMENT OF BOLT FROM ORIGIN? X=";X(I):INPUT "Y=";Y(I)
85 NEXT I
93 LET W=0
95 IF C=9.8 THEN W=.8167 : T=.21 : IM=42.6 : H=7 : B=2.09
100 IF C=12.25 THEN W=1.0208 : T=.314 : IM=48.48 : H=7 : B=2.194
105 IF C=14.75 THEN W=1.229 : T=.419 : IM=54.48 : H=7 : B=2.299
107 PRINT
110 PRINT "TYPE OF CHANNEL==C7-";C
115 PRINT "LENGTH OF CHANNELS (IN) ==";L
120 PRINT "NUMBER OF BOLTS USED==";N
121 PRINT "DIAMETER OF BOLTS (IN) ==";D
122 PRINT
125 PRINT "==PLACEMENT OF BOLTS FROM ORIGN?=="
130 FOR Z=1 TO N
135 PRINT "BOLT("Z") X="X(Z) ;"Y="Y(Z)
140 NEXT Z
145 CWT=2*W*L
150 PWT=77.83
155 A=3.1416*(D/2)^2
157 REM ++DETERMING CENTROIDS (BOTH X & Y)++
160 CEN=0
165 FOR J=1 TO N
170 CEN=CEN + X(J)
175 NEXT J
180 CENT=CEN/N
181 CEY=0
182 FOR B=1 TO N
183 CEY=CEY+Y(B)
184 NEXT B
185 CENY=CEY/N
186 REM ==CENTROID OF BOLTS W.R.T. ORIGIN==
187 FOR U=1 TO N
189 BX(U)=CENT-X(U)
190 BY(U)=CENY-Y(U)
```

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```
192 B(U)=SQR(BY(U)^2+BX(U)^2)
194 NEXT U
198 E=CENT+12.767
200 PD=CENT+12
203 CD=CENT+24-L/2
205 M=3125*E+PWT*PD+CWT*CD
206 PRINT
207 PRINT "THE APPLIED MOMENT (LB-I) ==";M
208 PRINT
210 PRINT "CENTROID POSITION X (IN) ==";CENT
212 PRINT "CENTROID POSTIION Y (IN) ==";CENY
214 PRINT
215 SB=0
220 FOR K=1 TO N
225 SB=SB+(B(K))^2
235 NEXT K
240 FD=M/(N*A)
243 PRINT
245 FOR R=1 TO N
250 FX(R)=M*BY(R)/(SB*A)
255 FY(R)=M*BX(R)/(SB*A)
263 NEXT R
265 FOR V=1 TO N
270 IF (X(V)-CENT)>0 THEN TR(V)=FY(V)+FD
275 IF (X(V)-CENT)<0 THEN TR(V)=FY(V)+FD
277 IF (X(V)-CENT)=0 THEN TR(V)=FD
280 NEXT V
285 REM && CALCULATING TOTAL FORCE ON EACH BOLT & ANGLE OF ATTACK &&
290 FOR Q=1 TO N
295 SF(Q)=SQR(TR(Q)^2+FX(Q)^2)
300 O(Q)=1.571-ATN(FX(Q)/TR(Q))
303 PRINT"TOTAL FORCE ON BOLT("Q") (LB)= = ";SF(Q):PRINT" AT AN ANGLE OF ";O(
RAD OR";O(Q)*180/3.1416"DEG"
305 NEXT Q
308 PRINT
310 REM @@ CALCULATING BEARING STRESS ON EACH BOLT @@
315 FOR P=1 TO N
320 BS(P)=SF(P)/(2*T*D)
323 PRINT "BEARING STRESS ON BOLT("P") (PSI) ==";BS(P)
325 NEXT P
350 PRINT
355 REM **CALCULATING SHEAR STRESS & BENDING STRESS IN CHANNELS**
360 SS=M*H*B/(2*IM)
365 SIG=M*H/(2*IM)
370 PRINT "SHEAR STRESS ON BEAMS=";SS
375 PRINT "BENDING STRESS ON BEAMS=";SIG
380 PRINT
470 INPUT "DO YOU WISH TO REPEAT (Y/N)?";F$
475 IF F$="Y" THEN 50
480 END
```

APPENDIX B

```
TYPE OF CHANNEL?? 9.8
LENGTH OF CHANNEL (IN) ?? 40
NUMBER OF BOLTS?? 3
DIAMETER OF BOLTS (IN) ?? 1.625
PLACEMENT OF BOLT FROM ORIGIN? X=? 3
Y=? 2.33
PLACEMENT OF BOLT FROM ORIGIN? X=? 3
Y=? 4.66
PLACEMENT OF BOLT FROM ORIGIN? X=? 10.5
Y=? 2.33

TYPE OF CHANNEL==C7- 9.8
LENGTH OF CHANNELS (IN). == 40
NUMBER OF BOLTS USED== 3
DIAMETER OF BOLTS (IN) == 1.625

==PLACEMENT OF BOLTS FROM ORIGN?==
BOLT( 1 ) X= 3 Y= 2.33
BOLT( 2 ) X= 3 Y= 4.66
BOLT( 3 ) X= 10.5 Y= 2.33

THE APPLIED MOMENT (LB-I) == 59067.09

CENTROID POSITION X (IN) == 5.5
CENTROID POSTIION Y (IN) == 3.106667


TOTAL FORCE ON BOLT( 1 ) (LB)= =
 11237.97
 AT AN ANGLE OF  1.523113 RAD OR
 87.26776 DEG
TOTAL FORCE ON BOLT( 2 ) (LB)= =
 11276.53
 AT AN ANGLE OF  1.666555 RAD OR
 95.48634 DEG
TOTAL FORCE ON BOLT( 3 ) (LB)= =
 6054.295
 AT AN ANGLE OF  1.482029 RAD OR
 84.91382 DEG

BEARING STRESS ON BOLT( 1 ) (PSI) ==
 16465.89
BEARING STRESS ON BOLT( 2 ) (PSI) ==
 16522.39
BEARING STRESS ON BOLT( 3 ) (PSI) ==
 8870.762

SHEAR STRESS ON BEAMS= 19411.72
BENDING STRESS ON BEAMS= 4852.93

DO YOU WISH TO REPEAT (Y/N)?? Y
```